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EVALUATION OF PHOSPHORUS AND ZINC INTERACTION EFFECTS ON WHEAT GROWN IN SALINE-SODIC SOIL

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The essentiality of phosphorus (P) as a macronutrient and that of zinc (Zn) as micronutrient for plants has been established long ago but their interactive effects on economic yield of crops are still controversial particularly in calcareous saline-sodic soils. Therefore, a pot experiment was conducted to evaluate the P-Zn interaction effects on wheat in saline-sodic soil. The treatments comprised of four levels of P (0, 25, 50 and 75 mg kg^{-1} soil) and three levels of Zn (0, 5 and 10 mg kg^{-1} soil) arranged in completely randomized design each with three replications. The results showed that total number of tillers, plant height, straw dry weight and 1000-grain weight was significantly ($P \leq 0.05$) higher in saline-sodic control closely followed by applied P at 75 mg kg^{-1} soil + Zn at 5 mg kg^{-1} soil ($P_{75}Zn_5$). While maximum Zn concentration in wheat straw and grains was observed in $P_{75}Zn_5$. The maximum ammonium-bicarbonate-diethylene-triamine-penta-acetic acid (AB-DTPA) extractable P and Zn in post-experiment soil was recorded with P at 75 mg kg^{-1} soil + Zn at 10 mg kg^{-1} soil ($P_{75}Zn_{10}$). Thus, application of P at 75 mg kg^{-1} soil along with Zn 5 mg kg^{-1} soil was the appropriate combination of P and Zn for substantial increase in growth and yield of wheat in saline-sodic soil.
Keywords: *Triticum aestivum*, P-Zn interface, salt stress, grain weight, tillering.

INTRODUCTION

Among cereal crops, wheat (*Triticum aestivum* L.) has prime importance and a principal diet of almost one third of the world's population. Wheat is ranked as a moderately salinity tolerant crop; however, yield parameters like tillering and grain weight were greatly affected by elevated external salinity (Naz *et al.*, 2015). Approximately 20% of the world cultivated area and about half of the world irrigated soils are inflated by salinity (Ghafoor *et al.*, 2004; Abbas *et al.*, 2016). The damaging effects of salinity on crop plants growth and yield are accompanied with less osmotic potential of soil solution (water stress), nutritive imbalance, specific ion effect (salt stress) or an amalgamation of all these factors (Ashraf and Haris, 2013; Hussain *et al*., 2016).

Deficiencies of N and P in agricultural soils are among major nutritional disorders; however, recent research revealed that micronutrient deficiencies like Zn, Fe and B are also hampering crop productivity (Rashid and Rayan, 2004). Use of high yielding crop cultivars and increased practice of macronutrient fertilizers (especially of N and P) have further accentuated the micronutrient deficiencies. The P-Zn deficiencies are prevalent nutritional limitations for crop production around the globe (Gill *et al*., 2004). Behaviour of P and Zn in soils and their availability to crop plants depend on physico-chemical properties of soil, crop species, climatic and agronomic practices (Aziz *et al*., 2012). Availability of both these elements is generally restricted in calcareous soils (Rahmatullah *et al*., 1994) and is highly pH dependent. Application of P fertilizers could persuade Zn deficiency in plants by changing soil and plant factors but a little is known about the specific mechanisms (Rafique *et al*., 2010).

Plants in saline media were found more sensitive to P toxicity, which indicates salinity increase P uptake and consequently Zn deficiency (Gunes *et al*., 1999). Calcareous, sodic and organic soils are likely to be deficient in Zn and Cu. Salinity and sodicity might affect the yield of crops in various ways including restriction in the absorption of certain nutrients. Salinity can change the micronutrient concentrations in plants, depending upon crop species and levels of salinity (Hu *et al*., 1997).

In salt-affected soils, P-Zn interaction in plants fall in two categories i.e., whether increasing P application decreases, or does not decrease Zn concentration in plant shoots.

Application of excessive P might also be an intention for decrease in the availability of Zn in different tissues of plants including grains (Iqbal *et al*., 2010). Earlier research has indicated that a low Zn with a high P application noticeably increased P concentration in plants, which may cause P toxicity and contribute to symptoms resembling Zn deficiency (Iqbal *et al*., 2012). However, very scarce information is available on the varying P-Zn application rates in saline-sodic soils in wheat. Therefore, it is necessary to evaluate the effect of soil available P on the Zn availability to plants particularly in calcareous saline-sodic soils, which could help to recognize the role of P and Zn interaction regarding nutritional quality of food crops.

MATERIALS AND METHODS

A pot study was conducted in the wire house having a glass covered roof (sides being open and only having iron wire screens with no control over temperature and humidity) at Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad. Salt-affected soil was collected from saline area of Sadhar by-pass, 8 km from Faisalabad. Soil was air–dried, passed through 2 mm sieve, thoroughly mixed and analyzed for physical and chemical properties as reported by Iqbal *et al*. (2015). The properties of soil used for present experiment are presented in Table 1.

Different treatments were arranged in completely randomized design (CRD) each with three replications. In each pot, 12 kg soil was filled. The treatments were included as P_0Zn_0 = saline-sodic control, $P_{25}Zn_0$ = P at 25 mg kg^{-1} soil, $P_{25}Zn_5$ = P at 25 mg kg^{-1} + Zn at 5 mg kg^{-1} soil, $P_{50}Zn_5$ = P at 50 mg kg^{-1} + Zn at 5 mg kg^{-1} soil, $P_{75}Zn_5$ = P at 75 mg kg^{-1} + Zn at 5 mg kg^{-1} soil, $P_{25}Zn_{10}$ = P at 25 mg kg^{-1} + Zn at 10 mg kg^{-1} soil, $P_{50}Zn_{10}$ = P at 50 mg kg^{-1} + Zn at 10 mg kg^{-1} soil, $P_{75}Zn_{10}$ = P at 75 mg kg^{-1} + Zn at 10 mg kg^{-1} soil.

Wheat crop was fertilized at 50 and 12.5 mg N and K kg^{-1} soil using urea and potassium sulfate, respectively. The source of P was single super phosphate, while Zn was applied as $ZnSO_4.7H_2O$ in solution form. The whole P, K, Zn and half of the N (by making solution), was applied at sowing while rest of N was applied in two equal splits; 30 and 45 days after sowing. Fifteen seeds of wheat cultivar Inqlab-91 were sown in each pot. After one week of germination, five plants per pot were retained and uprooted plants were crushed and mixed into the respective pots. Pumped ground water was used to irrigate the wheat crop. The chemical composition of pumped ground water used for irrigation is presented in Table 2.

At harvest maturity, the data about plant height, total number of tillers, grain and straw yields was recorded. Straw and grain samples were analyzed for P and Zn concentration. Plant (straw and grain) samples were digested in di-acid (3:1 mixture of nitric acid to perchloric acid) digestion mixture, from which P was determined via UV spectrophotometer (Champman and Pratt, 1961) and Zn via flame atomic absorption spectrometry (FAAS; Model Thermo S-Series, Thermo Electron Corporation, Cambridge, UK). The AB-DTPA extractable soil P and Zn was determined via FAAS, by extracting soil (10 g) with AB-DTPA solution (20 mL) adjusted to pH 7.60 (Soltanpour, 1985).

Table 1. Physico-chemical properties of soil used for experiment.

Parameter	Value
Textural class	Sandy clay loam
Sand (%)	63.3
Silt (%)	15.0
Clay (%)	21.7
pH_s	8.02
Saturation paste extract electrical conductivity (EC_e, dS m^{-1})	6.04
Total soluble salts (TSS, $mmol_c\ L^{-1}$)	70
Sodium adsorption ratio (SAR, mmol $L^{-1})^{1/2}$	20.07
CO_3^{2-} ($mmol_c\ L^{-1}$)	Absent
HCO_3^- ($mmol_c\ L^{-1}$)	8
Cl^- ($mmol_c\ L^{-1}$)	19
*SO_4^{2-} ($mmol_c\ L^{-1}$)	43
$Ca^{2+} + Mg^{2+}$ ($mmol_c\ L^{-1}$)	14.5
Na^+ ($mmol_c\ L^{-1}$)	55
K^+ ($mmol_c\ L^{-1}$)	0.5
Saturation percentage (SP, %)	29.4
Cation exchange capacity (CEC, $cmol_c\ kg^{-1}$)	9.3
** $Ca^{2+} + Mg^{2+}$ ($cmol_c\ kg^{-1}$)	4.4
Na^+ ($cmol_c\ kg^{-1}$)	1.6
K^+ ($cmol_c\ kg^{-1}$)	0.36
Organic matter (OM, %)	0.86
Lime contents ($CaCO_3$, %)	6.2
AB-DTPA extractable Zn (mg kg^{-1})	1.6
AB-DTPA extractable P (mg kg^{-1})	120.3
Total P (mg kg^{-1})	3718.2
Total Zn (mg kg^{-1})	72.1

*By difference, TSS - ($CO_3^{2-} + HCO_3^- + Cl^-$); **By difference, CEC – Exch. ($Na^+ + K^+$).

Table 2. Chemical composition of pumped ground water used for irrigation.

Parameter	Value
pH	7.9
EC (dS m^{-1})	0.61
TSS ($mmol_c\ L^{-1}$)	6.1
CO_3^{2-} ($mmol_c\ L^{-1}$)	Absent
HCO_3^- ($mmol_c\ L^{-1}$)	3.0
Cl^- ($mmol_c\ L^{-1}$)	2.5
*SO_4^{2-} ($mmol_c\ L^{-1}$)	0.60
$Ca^{2+} + Mg^{2+}$ ($mmol_c\ L^{-1}$)	4.1
Na^+ ($mmol_c\ L^{-1}$)	1.7
Residual sodium carbonate (RSC, $mmol_c\ L^{-1}$)	Nil
SAR (mmol $L^{-1})^{1/2}$	1.2
P (mg L^{-1})	Traces
Zn (mg L^{-1})	Traces

* By difference, TSS - ($CO_3^{2-} + HCO_3^- + Cl^-$)

***Statistical analysis*:** Data were statistically analyzed using M-STATC Version 1.10 computer software package. When there was a significant difference ($P \leq 0.05$) among the treatments for an attribute, Least Significant Difference (LSD) was calculated for the comparisons of their means (Steel *et al.*, 1997).

RESULTS

***Wheat growth and yield response*:** In present study, application of P and Zn treatments had a significant ($P \leq 0.05$) effect on the plant height (Table 3). The maximum (47.1 cm) height of wheat plants was recorded for the saline-sodic control (P_0Zn_0). With all the applied treatments, plant height decreased, being minimum (30.5 cm) with $P_{50}Zn_5$ and decrease was 35.2% over that of the control treatment. It was observed that plant height was decreased in pots where P at 25 mg kg^{-1} was applied to the saline-sodic soil. With applied Zn at 5 or 10 mg kg^{-1} soil by increasing rates of P (25, 50 or 75 mg kg^{-1} soil), a significant decrease in plant height was observed. Regarding the total number of tillers of wheat variety Inqalab-91, the applied treatments had a significant ($P \leq 0.05$) effect on total number of tillers of wheat. Total number of tillers of wheat was found maximum in the control treatment. All the treatments decreased the tillering capacity of wheat. A minimum number (7) of tillers was recorded with $P_{75}Zn_{10}$, decrease being 47.4% over that of control i.e., P_0Zn_0 (Table 3). Application of Zn at 5 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil), remained statistically similar.

A significant ($P \leq 0.05$) effect on 1000-grain weight of wheat by different P and Zn treatments was also recorded (Table 3). The maximum 1000-grain weight (31.4 g) of wheat was recorded in control. While, it was found minimum with $P_{75}Zn_5$ and decrease was 68.5% over that of control. Addition of Zn at 5 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil) did not improve the 1000-wheat grain weight. Application of Zn at 10 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1}) inconsistently affected 1000-grain weight of wheat. Similarly, applied P and Zn treatments had significant effect on straw dry weight of wheat (Table 3). Maximum wheat straw dry weight (10.1 g) was recorded in control, while it was found minimum with $P_{75}Zn_{10}$ and decrease was 75.0% over that of the control. Addition of Zn at 5 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1}) increased straw dry weight of wheat. However, application of Zn at 10 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil) decreased straw dry weight of wheat.

***Concentration of P and Zn*:** Nutrient concentration in wheat straw and grains were affected with addition of P and Zn in salt-affected soil. A significant effect on P concentration in wheat straw was recorded, being maximum (1024 mg kg^{-1}) with $P_{75}Zn_{10}$, which was higher by 86.2% over that of control (Table 4). Phosphorus concentration in wheat straw was found minimum (356 mg kg^{-1}) with $P_{75}Zn_5$, where it was decreased by 35.2% over that of control (Table 4). Addition of Zn at 5 mg kg^{-1} with increasing rates of P (25, 50 or 75 mg kg^{-1} soil) significantly decreased P concentration in wheat straw. Application of Zn at 10 mg kg^{-1} soil with increasing rate of P (25, 50 or 75 mg kg^{-1} soil) significantly increased P concentration in wheat straw. Similarly, P concentration in wheat grains was significantly affected by different applied P and Zn treatments. Maximum P concentration (4348.7 mg kg^{-1}) in wheat grains was recorded with the applied alone P at 25 mg kg^{-1} soil and was 42.7% higher over that of control (Table 4). Phosphorus concentration in wheat grains observed was minimum (2011.3 mg kg^{-1}) with $P_{25}Zn_5$, which was 33.9% less as compared to control.

Like P, Zn concentration in wheat straw was also affected by applied treatments, being maximum (55.5 mg kg^{-1}) with $P_{75}Zn_5$ which was 167.6% higher over that of control (Table 4). The Zn concentration in wheat straw was found minimum (20.0 mg kg^{-1}) with the applied alone P at 25 mg kg^{-1} soil and decrease was 3.4% over that of control (Table 4). Zinc concentration in wheat grains was maximum (67.1 mg kg^{-1}) with $P_{25}Zn_5$ and the increase was 37.8% over that of control (Table 4). Minimum Zn concentration (33.5 mg kg^{-1}) in wheat grains was recorded with $P_{25}Zn_5$ and decrease was 31.1% compared to control.

Table 3. Effect of varying levels of applied P and Zn on wheat growth and yield.

Treatment	Plant height (cm)	Number of tillers	1000-grain weight (g pot^{-1})	Straw dry weight (g pot^{-1})
P_0Zn_0 = saline-sodic control	47.1 a	13.3 a	31.4 a	10.1 a
$P_{25}Zn_0$ = P at 25 mg kg^{-1} soil	43.7 ab (-7.1)	9.6 b (-27.5)	27.7 ab (-11.8)	6.3 b (-37.1)
$P_{25}Zn_5$ = P at 25 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	33.0 cd (-29.8)	8.6 bc (-35.0)	10.8 c (-65.5)	3.2 c (-67.9)
$P_{50}Zn_5$ = P at 50 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	30.5 d (-35.2)	8.0 bc (-39.9)	9.8 c (-68.5)	4.4 bc (-56.1)
$P_{75}Zn_5$ = P at 75 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	41.9 b (-11.0)	9.0 bc (-32.4)	30.0 a (-4.4)	8.5 a (-15.6)
$P_{25}Zn_{10}$ = P at 25 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	34.3 cd (-27.2)	7.3 c (-45.0)	26.8 ab (-14.5)	3.0 c (-69.7)
$P_{50}Zn_{10}$ = P at 50 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	37.3 c (-20.7)	7.6 c (-42.5)	23.2 b (-26.1)	3.4 c (-66.1)
$P_{75}Zn_{10}$ = P at 75 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	31.7 d (-32.6)	7.0 c (-47.4)	27.6 ab (-12.0)	2.5 c (-75.0)
	$LSD_{0.05}$ = 4.4	$LSD_{0.05}$ = 1.8	$LSD_{0.05}$ = 5.2	$LSD_{0.05}$ = 2.1

Values in parenthesis are percent increase (+) or decrease (-) over that saline-sodic control (P_0Zn_0) treatment. Means sharing dissimilar letter in a column are statistically significant ($p \leq 0.05$, n = 3).

Table 4. Effect of varying levels of applied P and Zn on concentration (mg kg^{-1}) of P and Zn in wheat straw and grain.

Treatment	P concentration in straw (mg kg^{-1})	P concentration in grain (mg kg^{-1})	Zn concentration in straw (mg kg^{-1})	Zn concentration in grain (mg kg^{-1})
P_0Zn_0 = saline-sodic control	549.7 d	3046.9 bc	20.7 d	48.7 b
$P_{25}Zn_0$ = P at 25 mg kg^{-1} soil	674.4 c (22.6)	4348.7 a (42.7)	20.0 d (-3.4)	42.6 bc (-12.3)
$P_{25}Zn_5$ = P at 25 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	700.6 c (27.4)	2011.3 d (-33.9)	35.0 c (68.7)	35.5 c (-26.9)
$P_{50}Zn_5$ = P at 50 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	683.9 c (24.4)	2499.1 cd (-17.9)	41.3 bc (99.1)	33.5 c (-31.1)
$P_{75}Zn_5$ = P at 75 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	356.0 e (-35.2)	4105.0 a (34.7)	55.5 a (167.6)	67.1 a (37.8)
$P_{25}Zn_{10}$ = P at 25 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	855.2 b (55.5)	3263.3 b (7.1)	54.9 a (164.6)	61.2 a (25.8)
$P_{50}Zn_{10}$ = P at 50 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	750.9 bc (36.6)	3061.4 bc (0.5)	38.0 c (83.1)	49.8 b (2.4)
$P_{75}Zn_{10}$ = P at 75 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	1024.0 a (86.2)	2856.3 bc (-6.2)	46.0 ab (122.0)	51.2 b (5.1)
	$LSD_{0.05}$ = 104.8	$LSD_{0.05}$ = 535.7	$LSD_{0.05}$ = 9.4	$LSD_{0.05}$ = 9.9

Values in parenthesis are percent increase (+) or decrease (-) over that saline-sodic control (P_0Zn_0) treatment. Means sharing dissimilar letter in a column are statistically significant ($p \leq 0.05$, n = 3).

Table 5. Effect of varying levels of applied P and Zn on AB-DTPA extractable P and Zn (mg kg^{-1}) in post-wheat soil.

Treatment	AB-DTPA extractable P (mg kg^{-1})	AB-DTPA extractable Zn (mg kg^{-1})
P_0Zn_0 = saline-sodic control	19.8 c	0.9 d
$P_{25}Zn_0$ = P at 25 mg kg^{-1} soil	22.7 bc (13.7)	1.0 d (12.8)
$P_{25}Zn_5$ = P at 25 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	27.1 ab (35.9)	3.9 b (307.2)
$P_{50}Zn_5$ = P at 50 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	28.1 a (40.6)	2.9 c (206.2)
$P_{75}Zn_5$ = P at 75 mg kg^{-1} + Zn at 5 mg kg^{-1} soil	27.2 ab (36.5)	3.5 bc (264.5)
$P_{25}Zn_{10}$ = P at 25 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	26.4 ab (32.3)	4.8 a (407.2)
$P_{50}Zn_{10}$ = P at 50 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	25.8 ab (29.2)	5.5 a (473.9)
$P_{75}Zn_{10}$ = P at 75 mg kg^{-1} + Zn at 10 mg kg^{-1} soil	28.9 a (44.7)	4.7 a (393.7)
	$LSD_{0.05}$ = 0.8	$LSD_{0.05}$ = 4.4

Values in parenthesis are percent increase (+) over that saline-sodic control (P_0Zn_0) treatment. Means sharing dissimilar letter in a column are statistically significant ($p \leq 0.05$, n = 3).

A significant effect of applied treatments on the AB-DTPA extractable P in the post-wheat soil (Table 5) was observed, being maximum (28.9 mg kg^{-1}) with the application of $P_{75}Zn_{10}$. The increase in AB-DTPA extractable P was 44.7% over that of control. However, it was minimum (19.8 mg kg^{-1}) in the control treatment. Similarly, a significant ($P \leq 0.05$) effect of different treatments on the AB-DTPA extractable Zn in the post-wheat soil (Table 5) was recorded, being maximum with $P_{50}Zn_{10}$ and the increase by 473.9% over that of control. The AB-DTPA extractable Zn in post-wheat soil was found minimum (0.9 mg kg^{-1}) in control treatment.

DISCUSSION

In present study, the combined effects of soil salinity and increasing rates of P and Zn nutrition of wheat were investigated. Different wheat growth parameters such as plant height, number of tillers, 1000-grain weight or straw dry weight (Table 3) improved with applied P at 75 mg kg^{-1} + Zn at 5 mg kg^{-1} soil due to the reason that moderate soil salinity may even interact positively with the plant nutrients and could enhance the metabolism resulting in normal plant growth (Iqbal *et al*., 2012). At applied Zn at 10 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil) decreased plant height (Table 3) might be owing to antagonistic effect between P and Zn at their higher application rates in the presence of salinity. Bernstein *et al.* (1974) described that the salinity effect is greater at the higher fertility levels, indicating that salts used to increase fertility may themselves have an additive effect on the adverse response to salinity. El-Mahi and Mustafa (1980) reported that saline soils retained more P compared to non-saline soils. Phosphates and chlorides are absorbed by essentially the same mechanism; excess concentration of Cl^-, as found in highly saline soils, may adversely affect the absorption of phosphates because of competitive inhibition (Chhabra *et al*., 1976; Iqbal *et al*., 2012). According to Grieve *et al.* (1993) adverse effect occurs early in the plant life as salts hinder the development of primordia which determines the number of tillers per plant. It is possible that the applied nutrients could not show their influence because of depressive effect of salinity. With Zn at 10 mg kg^{-1} soil by increasing the rates of applied P (25, 50 or 75 mg kg^{-1} soil), there were no significant differences in total number of tillers of wheat (Table 3). The maximum 1000-grain weight of wheat (Table 3) recorded for the control might be attributed to the reason that soil used in present experiment had already sufficient P concentration to support normal plant growth and ultimately yield of wheat. El-Mahi and Mustafa

(1980) reported that saline soils generally contain more P than non-saline soils. Increased yield of wheat (Table 3) with P at 75 mg kg^{-1} soil + Zn at 5 mg kg^{-1} soil was because moderate soil salinity may even interact positively with the plant nutrients and could enhance the metabolism resulting in normal plant growth (Dregne and Mojallali, 1969; Hassan *et al.,* 1970; Iqbal *et al*., 2012). Phosphorus promoted grain development that resulted in higher 1000-grain weight. Likewise, application of Zn at 10 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil) inconsistently affected 1000-grain weight of wheat (Table 3). The antagonistic effect between P and Zn at their higher rates in the presence of salinity might be the main reason. Higher concentration of P in plants could interrupt different metabolic processes like photosynthesis, respiration and nitrogen assimilation, ultimately resulting in poor growth leading to low biomass. Straw dry matter production at specific level of nutrients is regarded as the product of plant mechanism involving acquisition, translocation and utilization of that nutrient (Iqbal *et al*., 2012). Increasing salinity of irrigation water decreased shoot dry matter, especially without $ZnSO_4$ application (Khosgoftar *et al.,* 2004). Combined application of P and Zn with saline irrigation water improved dry matter accumulation and P utilization in wheat compared with their single application (Dravid, 1996).

In present study, maximum P concentration in wheat straw (Table 4) was observed in pots where P at 75 mg kg^{-1} soil + Zn at 10 mg kg^{-1} soil were applied, indicating no antagonistic interaction between P and Zn absorption by wheat plant. This type of interaction between Zn and P concentration seems due to moderately Zn deficient nature of soil. Antagonistic interaction between Zn and P concentration could occur only when Zn deficient soil changed symbiotic association between roots of host plant and mycorrhizal fungi (Lambert *et al*., 1979). The exudation of reducing sugar was decreased, which was used by the mycorrhizae as their food, with sufficient amount of readily available P in Zn deficient soil and due to pH changes in rhizosphere soil by plant roots. In alkaline Zn deficient soil, plant roots absorb P and release OH^- to balance its membrane charge. These OH^- ions tend to increase soil pH at micro level that further restricts Zn absorption by plant roots. However, antagonistic interaction between P and Zn was reported in literature. So, present results are in contrast with those reported by Ali *et al*. (1990), Erdal *et al*. (2002) and Zhu *et al*. (2001). This contradiction in results might have been due to variation in fertility status of soil, soil salinity/sodicity and crop plant species.

A consistent increase in wheat straw and grain P concentration with increasing application rate of Zn combined with P is in agreement with the findings of Zhu *et al*. (2001). They also reported an increase in shoot P concentration of winter wheat with increasing Zn application rates. Increased P concentration with soil-applied Zn might be due to the reason that when Zn and P were in appropriate ratio, these might show synergistic effect. AbdEl-Hady (2007) reported that N, P and K concentration and their absorption by barley plants increased with increasing Zn application rates. The maximum P concentration (4348.7 mg kg^{-1}) in wheat grains (Table 4) was observed with P at 25 mg kg^{-1} soil which seems that plants respond positively to application of P, resultantly more P accumulated in grains. Addition of Zn at 5 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil) non-significantly increased the P concentration in wheat grains. Modaihsh *et al*. (1996) reported that Zn application at low rates of P would decrease P concentration in plant parts. Although at a given level of Zn, when high rates of P were applied to soil, there was a slight increase in P concentration in wheat grains. Application of Zn at 10 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil) inconsistently decreased P concentration in wheat grains. It might be due to antagonistic effect between P and Zn at their higher application rates. Zhu *et al*. (2001) concluded that reduction in P concentration was associated with high Zn supply. Such a negative interaction between P and Zn was indeed documented in plants (Takkar *et al.,* 1976; Sumner and Farina, 1986).

The maximum Zn concentration in wheat straw and grain (Table 4) with P at 75 mg kg^{-1} soil + Zn at 5 mg kg^{-1} soil might be due to the reason that Zn and P in appropriate ratio that might respond synergistically. Hu and Schmidhalter (2001) reported that in saline environment, Zn concentrations in plants might dependent upon the prominence of macronutrients, levels of salinity and the plant tissue. Marschner (1995) reported that increase in P and Ca concentrations in the growth medium decreased the concentration of Zn in normal soils. The evidence is in contradictory with the present study results because of salt-affected soil conditions. In control plants Zn concentration was minimum due to binding of Zn with complexes of different ions in saline soil. Khoshgoftar *et al*. (2004) described that salinity decreased the total Zn and free Zn^{2+} concentrations in soil solution and decreased the Zn concentration in wheat shoot. It was recorded that Zn concentration in wheat straw (Table 4) decreased in pots where P at 25 mg kg^{-1} soil was applied to salt-affected soil might be owing to applied P caused a decrease in Zn concentration in plants (Zhu *et al*., 2001) partly due to growth dilution. Buekert *et al*. (1998) reported that use of undue P also caused a decrease in concentration of Zn in grains as well as other plant tissues. As metabolism increased, Zn concentration increased due to catalytic effect. The applied P had a inconstant influence on Zn uptake by wheat as the Zn concentration increased with the use of 25 µg P g^{-1} soil (moderate), owing to superior growth at applied level of P (Imtiaz *et al*., 2006). Hu and Schmidhalter (2001) reported that changes in Zn concentration in wheat under saline conditions might be influenced by the status of macronutrients, salinity and the plant tissue.

At low rate of Zn i.e., 5 mg kg^{-1} soil with increasing rates of P (25, 50 or 75 mg kg^{-1} soil), statistically similar AB-DTPA extractable P in post-wheat soil (Table 5) was recorded. At high rates of Zn i.e., 10 mg kg^{-1} soil with increasing rates of applied P (25, 50 or 75 mg kg^{-1} soil), non-significant increase in AB-DTPA extractable P in post-wheat soil was observed. A slight increase in AB-DTPA extractable P in post-wheat soil with increasing application rate of Zn combined with P is in line with the findings of

Mian *et al*. (2001). They reported higher soil P and Zn values at the harvest of last wheat crop in the treatment receiving higher P and Zn values compared to other treatments. Pierzynski and Schwab (1993) reported that addition of soluble phosphorus compounds increased soil pH due to ligand-exchange (OH^- ions) and phosphate adsorption reactions. Iqbal *et al*. (2012) reported increased P solubility with an increase in pH in a Na-dominated clay system, while decreased Ca-dominated system. They also reported that sodic and saline-sodic soils usually contain higher available P than the normal soils because high concentration of $NaCO_3$ results in the formation of $NaPO_4$, which is more soluble. It was observed that AB-DTPA extractable Zn in post-wheat soil (Table 5) decreased in pots where P at 25 mg kg^{-1} soil was applied. At low rates of Zn at 5 mg kg^{-1} soil with increasing rates of applied P (25, 50 or 75 mg kg^{-1} soil), statistically similar Zn (except for P at 50 mg kg^{-1} soil + Zn at 5 mg kg^{-1} soil) was recorded. Mian *et al*. (2001) also reported a statistically no P induced Zn differences in soil test values. There was a tendency of increased soil test Zn concentration due to higher P application rate. Brown *et al*. (1970) reported that rate of P did not greatly affect extractable Zn, but tended to increase Zn rather than decrease in two alkaline soils. Singh *et al*. (1987) reported that higher application of $ZnSO_4$ increased the DTPA-Zn of soil. Therefore, it might be expected that increased Zn concentration in soil will resultantly increase its concentration in wheat.

Conclusions**:** It can be concluded from the present study that application of varying rates of P and Zn in saline soils helped in increasing the wheat growth and yield by directly providing P and Zn. Moreover, application of P fertilizers may be missed in the initial years of alkali soil reclamation but their addition was must in saline soils. Nevertheless, application of P at 75 mg kg^{-1} soil along with Zn at 5 mg kg^{-1} soil was the appropriate combinations of P and Zn for substantial increase in growth and yield of wheat in saline-sodic soils. Physiological, biochemical and genetic studies are still required regarding P-Zn interactions in diverse crops and their species/genotypes for crop and site-specific fertilizer recommendations and nutritional management particularly in different types of salt-affected soils.

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